Selective Radiation Measurement for Safety Evaluation on Base Stations

Mustafa Ergin ŞAHİN[1, ♣], Nilüfer AS[1], Yasin KARAN[1]

[1]*Recep Tayyip Erdoğan University, Department of Physics, Rize, TURKEY*

ABSTRACT

In this paper, general information about unionized radiation, standards and measurement routines for wireless communication systems, electromagnetic fields and antenna structures are given. The safety of mobile phones has been evaluated in terms of specific absorption ratio (SAR). This SAR values have been defined after long discussions by international standard organizations. Electromagnetic compatibility (EMC) measurements were performed with a compact spectrum analyzer device, measures 400MHz - 6GHz bandwidth, and a triaxial antenna. Electromagnetic fields and power flux density values are measured, and compared with ICNIRP standard curve safety values. These measured values are observed and separated for two base stations at the same point. Measured electric field and power density values are plotted with respect to distance from base station tower, and compared with theoretical results. Finally, the safety distance is defined and calculated.

Key Words: *Electromagnetic compatibility, selective radiation measurement, spectrum analyzer measurement technique, safety evaluation, specific absorption ratio, global communication systems, base stations.*

1.INTRODUCTION

With the increase of wireless communication devices exponentially over last decades, the health risk due to electromagnetic fields have became a focus of public concern. This public concern regarding human safety was associated with raise electromagnetic waves. This issue has led to an important field of study in EMC research. The public perception of increase in ambient background of radio frequency (RF) or high frequency (HF) radiation in the environment has developed in to a public concern. As a result, this required an engagement of public health authorities to quantify these fields by measurement [1-3].

This article will focus on the issue of measurement of high frequency electromagnetic field which is used in wireless communication and television receivers. This type of measurement is also called as non-ionizing radiation measurement. Nucleus particle radiation (as in very high frequency particle radiation) does not occur in high electromagnetic field. The frequency bandwidth and wavelengths for different events are shown in Figure 1 [4, 5].

In practice, it's impossible to measure SAR values directly. Therefore, measurement practice introduces electric and magnetic field strength in near field, and

♣Corresponding author, e-mail: mustafaerginsahin@yahoo.com

power density in far field in addition to absorbed energy. The statistically averaged SAR values obtained over 6 minutes is specified in safety guidelines. This duration is based on the bio-electromagnetic research and is used in all safety measurements as a standard value [6-8].
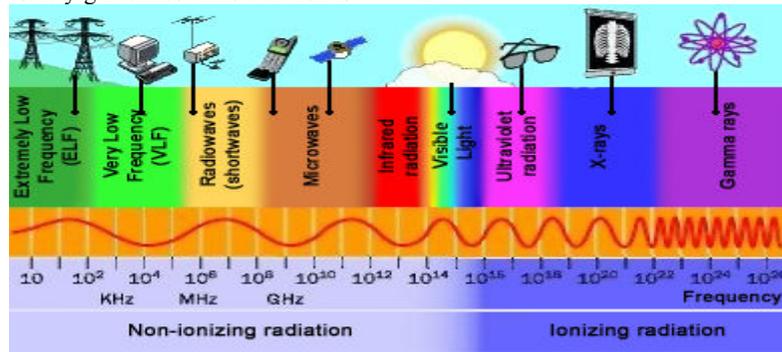

Figure 1. The frequency bandwidth and wavelengths for different events.

In a research by Salama et al. [9], 24 adult male rabbits are used to find the accumulating effects of exposure to electromagnetic radiation emitted by a conventional mobile phone (in stand-by position). These rabbits are equally divided into three groups to measure sperm count under different conditions. One of the rabbit groups was subjected to mobile phone electromagnetic field for 8 hours per day along 12 weeks. After 12 weeks, rabbits' sperm count was measured as nearly 50% of initial count. This study indicated significant decrease in sperm count and motility at weeks 8 and 10 because of exposure to mobile phone emission, respectively [9-11].

Global System for Mobile Communications (GSM) was introduced in the 1980s to have a new cellular radio interface. GSM system is a kind of network combined with base stations. Base stations communicate with cell phones by RF signal using electromagnetic (EM) waves. Carrier frequencies of signals used in GSM are 900 MHz and 1800 MHz for different operators. UMTS, 3G network's carrier frequency, on the other hand, is 2100 MHz [12, 13].

EMC measurements are made with a compact spectrum analyzer device, (SRM 3006, Narda Safety Test Solutions GmbH, Pfullingen, Germany) capable of measuring the 400 MHz- 6 GHz frequency range with a triaxial coil antenna. Electric field is converted to both magnetic field and power flux density values using a standard table for far measurements. These measured and calculated values are compared with the SAR values, and ICNIRP or other standard curves. These curves can differently be evaluated to set the safety values in different countries [14, 15].

This research, in experimental part, measured EM field values are separated for two base stations available at the same location. Measured electric field and power density values are plotted by distance from base station tower and compared with theoretical results. Finally, safety distance is calculated and checked with regulations.

2. ELECTROMAGNETIC FIELD AND ANTENNAS

Electromagnetic waves consist of electric and magnetic field components which are moving waves along perpendicular directions to each other. These are periodic, and the wave propagation direction is in the third axis which is perpendicular to both of them. The interactions of electric and magnetic field components of electromagnetic field with each other and with the matter are examined by a set of equation called Maxwell's equations. Equation 1 and 2 shows Gauss law in electric field and magnetic field, respectively. Equation 3 and 4 shows Faraday induction law and Ampere law, respectively. It says that a source of emitting time varying electric field induces magnetic field. A time varying electric field generates a time varying magnetic field or vice versa. Both electric and magnetic field components oscillate in phase perpendicular to each other [16, 17].

$$\oint \vec{E}.\overrightarrow{dA} = \frac{q}{\varepsilon_0} \tag{1}$$

$$\oint \vec{B}.\overrightarrow{dA} = 0 \tag{2}$$

$$\oint \vec{E}.\overrightarrow{dS} = -\frac{d_{\varphi B}}{d_t} \tag{3}$$

$$\oint \vec{B}.\overrightarrow{dS} = \mu_0 I + \mu_0 \varepsilon_0 \frac{d_{\varphi E}}{d_t} \tag{4}$$

The electromagnetic field is the combination of these electric and magnetic fields. Fundamental dipole equations are depicted in Table 1.

Table 1. Fundamental dipole equations.

High Frequency	Field Parameters
$S = E * H$ (W/m²)	S = Power flux density
$E = Z_0 * H$ (V/m)	E = Electric field strength
$H = E / Z_0$ (A/m)	H = Magnetic field strength
Low Frequency	Z_0 = 377 ohm (space impedance)

$B = \mu_0 * H$ $\mu_0 = 4*\pi*10^7$ Vs/Am	B=Magnetic flux density or magnetic induction (in Tesla or Gauss)

Periodical electric field and magnetic field equations are shown in Equation 5 and 6 respectively. In these equations, E_0 and B_0 are electric and magnetic fields' maximum values and $k = 2\pi/\lambda$ gives wave number.

$$E = E_0 sin(kx - \omega t) \qquad (5)$$

$$B = B_0 sin(kx - \omega t) \qquad (6)$$

Two main zones are used for measurement; near zone and far zone. The zone limit is defined with the distance from field source (R). If R is less than *3λ,* it is accepted as near field. If wavelength (λ) is less than the diameter (D) of the antennas (e.g. radars) then R is bigger than $2D^2/\lambda$ for far field [2]. For far zone, E and H fields in phase as shown in Figure 2 (a). Since other component of EM wave can be computed, measuring of one component of EM wave can be enough to find the EM wave for far zone. For near zone, *E* and *H* fields decoupled and are not in phase as shown in Figure 2.b. The two quantities must be measured separately.
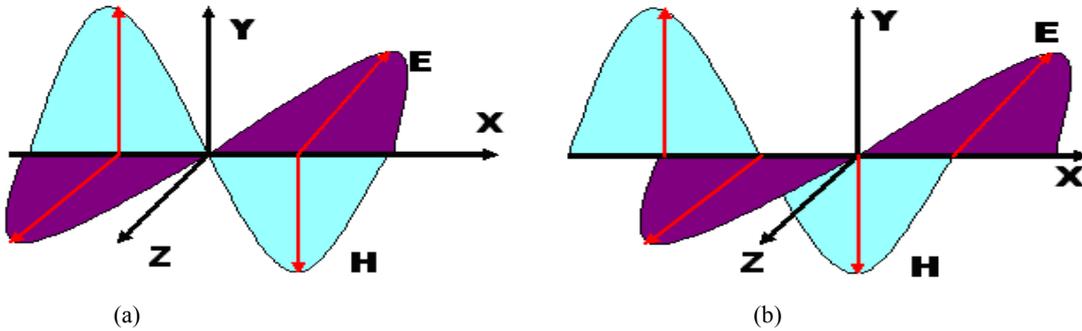

(a)   (b)

Figure 2. (a) E and H fields in phase for far zone. (b) E and H fields did not in phase for near zone.

Magnetic fields are measured by coils as sensors. The induced current corresponds to the field strength. Figure 3 shows triaxial array of three coils, each covering an area of 100 cm² to conform to European standards.
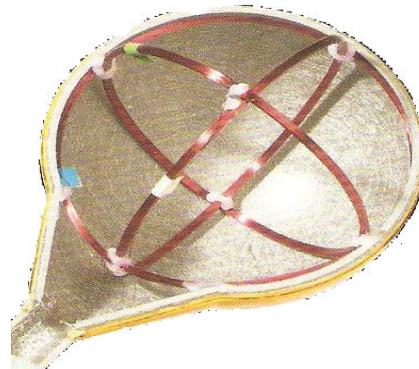

Figure 3. Triaxial array of three coils antenna.

Electric fields are measured using sensors based on principle of dipoles or capacitors. The output voltage is proportional to the field strength. Triaxial dipoles arrays are for the high frequency range measurements, capacitor arrays are for the low frequency range measurements. For far zones, magnetic field is computed from electric field by using equations in Table 1, and for near field the two quantities must be measured separately. The total electric field is obtained with Equation 7 using three axis measurements.

$$E_{tot} = \sqrt{E_x^2 + E_y^2 + E_z^2} \qquad (7)$$

3. STANDARDS AND GUIDELINES

HF or RF electromagnetic fields can heat all the body or parts of the body depending on the frequency. As short term effect, heating and burning of tissue might occur. The body and body parts act as a lossy antenna in 0.75 m to 2 m wavelength range. This wavelength is the resonance frequency of the body. The body's qualitative absorption curve as a function of radio frequency is shown in Figure 4.
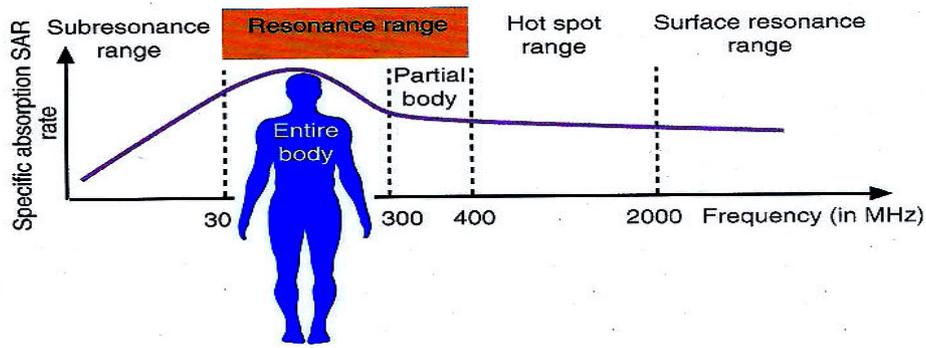
Figure 4. The body's absorption curve.

Presently, existing standards and guidelines (e.g. ICNIRP, IEEE, WHO) take specific absorption ratio (SAR) as a reference parameter. This rate is defined as RF electromagnetic energy absorbed in the body for 6 minutes. In practice, it's impossible to measure SAR value directly. Therefore, recommended measurement practice is introduced as exposure levels in terms of unperturbed electric and magnetic field strength in the near field and power density in the far field, in addition to absorbed energy units. Since the guidelines and the standards have been developed on the basis of bio electromagnetic research in the field of thermal effects,

the spatial and time-averaged values are needed to be measured [18].

Depending on absorption curve, ICNIRP guidelines for electric field is defined as shown in Figure 5. This electric field curve can be converted magnetic field curve and power density curve easily for far field region using a conversion table and the formulas in Table 1. Two guidelines are shown in Figure 5, one of them is valid for general public and the other one is for continuously exposed to electromagnetic radiation occupations. For these occupations' limits are higher than public standards.
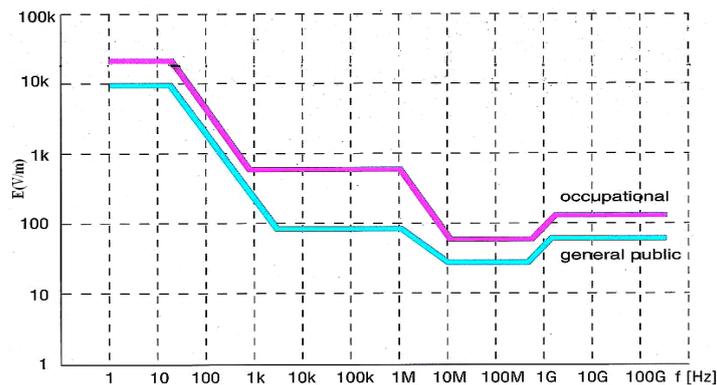

Figure 5. ICNIRP guidelines for electric field.

Turkish public safety evaluation standards are defined using ICNIRP guidelines which are 25% level of ICNIRP standards, and these are declared in 2009, after several

regulations. Table 2 shows safety evaluation standards that defines the safety values and it is used when measurement devices are used [2, 19].

Table 2. Safety evaluation field standards.

Frequency Range (MHz)	E - Field Strength (V/m)		H - Field Strength (A/m)		B - Magnetic Flux Density (µT)		Equivalent Wave Power Density (W/m²)	
	For one device limit value	Total limit value	For one device limit value	Total limit value	For one device limit value	Total limit value	For one device limit value	Total limit value
0,010-0,15	22	87	1,3	5	1,5	6,25	-	-
0,15-1	22	87	1,18/f	0,73/f	0,23/f	0,92/f	-	-
1-10	$22/f^{1/2}$	$87/f^{1/2}$	0,18/f	0,73/f	0,23/f	0,92/f	-	-
10-400	7	28	0,02	0,073	0,023	0,092	0,125	2
400-2000	$0,341\,f^{1/2}$	$1,375f^{1/2}$	$0,0009\,f^{1/2}$	$0,0037\,f^{1/2}$	$0,001\,f^{1/2}$	$0,0046\,f^{1/2}$	f/3200	f/200
2000-60000	15	61	0,04	0,16	0,05	0,2	0,625	10

4. MEASUREMENT SYSTEM AND ROUTINES

RF field probes are often preferred for EMF measurement because of being fast, simple and convenient. In general, RF probes have wide operation frequency but not selective. For frequency selective measurement, it is needed to have an antenna and a spectrum analyzer operated in a sweeping time mode over the frequency range of interest. In these measurements, NARDA SRM 3006 device is used, which can measure 400 MHz - 6 GHz bandwidth with a triaxial antenna. This device is included all the equipment and software in it as a compact system. The measurement results are recorded in device and can be uploaded to a computer easily using its special software. The calibrations are made for antenna, connection wire and spectrum analyzer separately. With

the GPS system in it, coordinates are defined easily. Using the unit change operations electric field, magnetic field and power density can be converted each other and the results are shown on the screen how you wanted.

In Figure 6, a measurement is performed at RTE University campus area where TV transmitter towers and base stations are located in a near hill. The measurement is performed on the roof of the highest building in the university campus where the distance is the nearest point from the antenna is horizontally. The electric field spectrum measurement average value results from 420 MHz to 2.17 GHz are shown in Figure 6. Turkish standard curve of limit for electric field is not seen in the figure because the measured electric field values are much less than them.
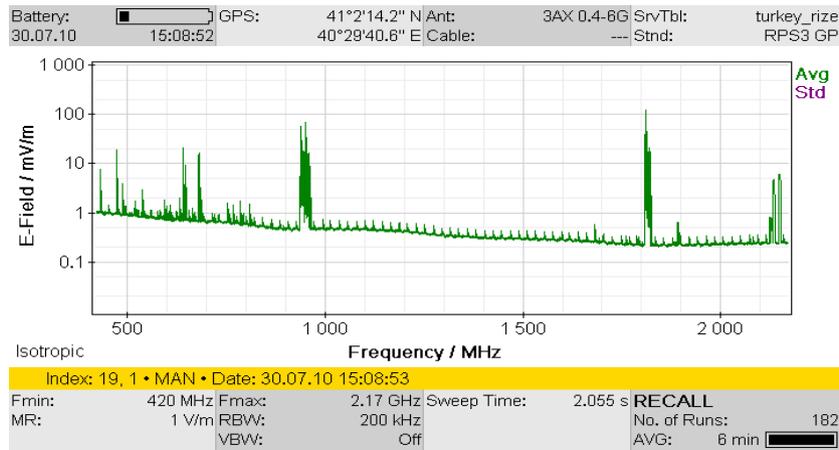

Figure 6. Electric field measurement results.

Another property of device is that it can select the spectrums for different services and can show the results of maximum, average, actual, maximum average of signals as a table or a bar graphic. Also, it can compare the results with the standard curve on the screen. For the

spectrum in Figure 6, selected frequency services electric field and total electric field are shown as a table in Figure 7(a). The bar graphic of this table is shown in Figure 7(b) to compare the values easily.
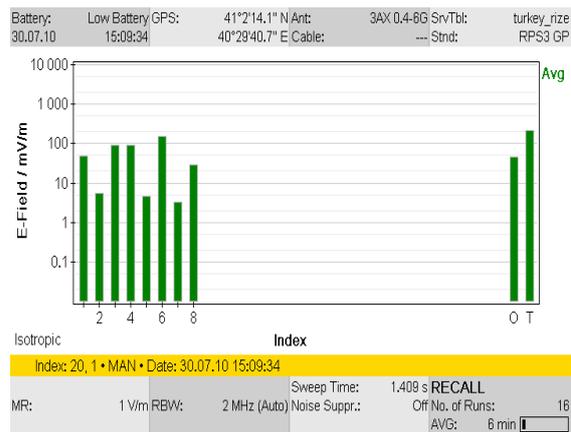
(a)   (b)

Figure 7. (a) Electric field detailed service table. (b) Electric field detailed bar graphic.

Safety distance for an antenna is calculated using the Equation 8. In this equation, P_o is the device output power, G is the antenna gain as dB, and E is the electrical area limit value. If it is not easy to measure E field near the antenna, safety distance can be estimated by the measured E fields for different distances and formula

below. Then, it can be compared with the theoretical safety distance.

$$d = \frac{\sqrt{30.P_o.10^{G/10}}}{E} \; (meter) \tag{8}$$

The measured electric field values by the SRM device can be converted magnetic field values and power density values.It can be automatically done in the SRM device and seen in the screen of the device. Equation 9 and Equation 10 are the formules to evaluate the Power density and Magnetic field from Electric field, respectively.

$$P = \frac{E^2}{120\pi} \; (^W/_{m^2})$$ (9)

$$H = \sqrt{\frac{P}{377}} \; (^A/_m)$$ (10)

5. GSM (GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS) AND BASE STATIONS

The GSM system network can be divided into three subgroups that are interconnected using standardized interfaces: Mobile Station (MS), Base Station Subsystem (BSS), and Network Subsystem (NSS). Figure 8 shows the GSM system map. Shortly, NSS controls the network traffic flow. BSS is the link between MS (cell phones) and NSS. BSS has two units; the Base Station Controller (BSC) and the Base Transceiver Station (BTS). BSC controls the communication routings, handover between base stations. BTS is radio signal transmitter and receiver parts of GSM system. It provides wireless communication between Mobil stations and wireless network with its antenna. NSS has two units; Mobile Switching Center (MSC) and Gateway MSC (GMSC). This network subsystem supply connection with the other communication system [12, 13].
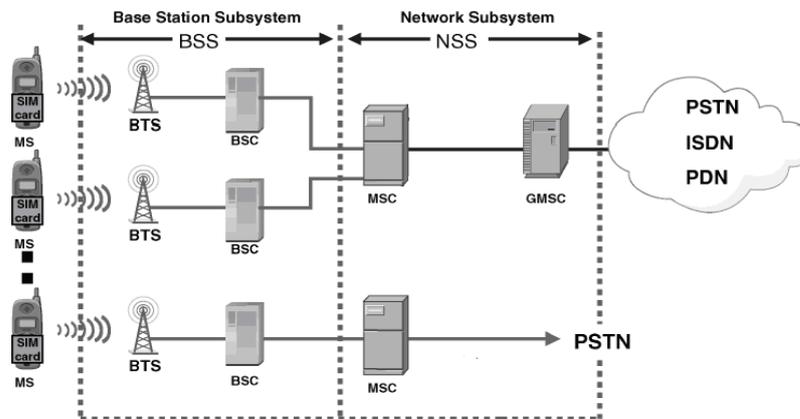

Figure 8. General structure of GSM system.

GSM system coverage is combined from cells, and each cell has a base station. Every Base Station has traffic capacities. At a time, particular number of calls can be served by base station. Therefore, because of the population, more base stations can be seen in city centers, while less base stations can be enough for rural areas. This situation affects the signal power each base station propagated. In the rural areas, base stations produce more power to reach further mobile stations. In general, BTS's have 3 directed antennas and so each has 120^0 propagation pattern. There are also base stations which have 2 antennas with 180^0 propagation patterns or 4 antennas with 90^0 propagation patterns. Each base station has a coverage area depending on its propagation power. Figure 9(a) shows cell structure of base station and Figure 9(b) shows antennas propagation pattern.
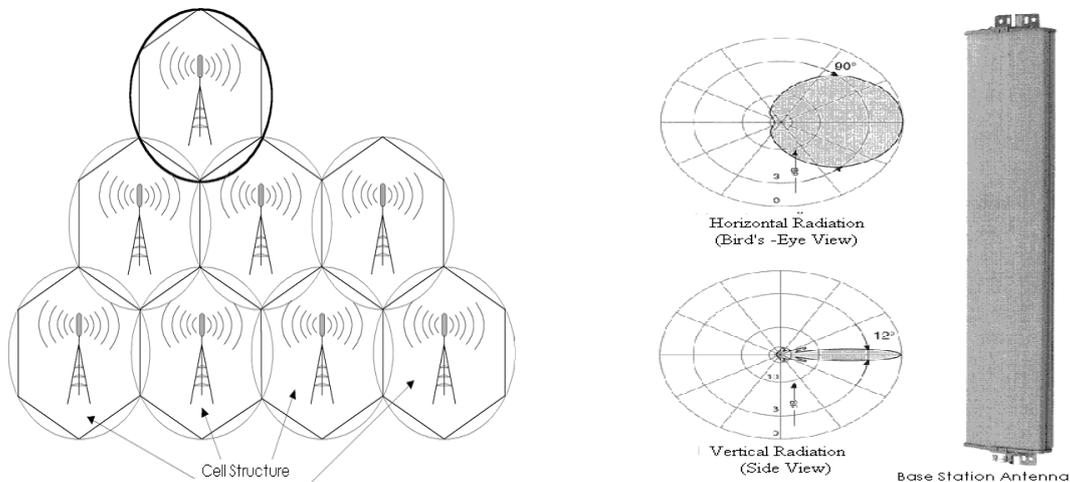

Figure 9. (a) Cell structure of base station.   (b) Antennas propagation pattern.

As it is seen in Figure 9(b) signal propagated horizontal, and has small angle on vertical direction. It can be understood from the Figure 10 that on the place under the antenna, there are less EM signal. By going further, RF signal power increases because it gets close to coverage area. By going furtherer, RF signal power or electromagnetic area decreases because of the increases of distance. Figure 10 shows the EM field radiation from the base station with distance approximately [20, 21].
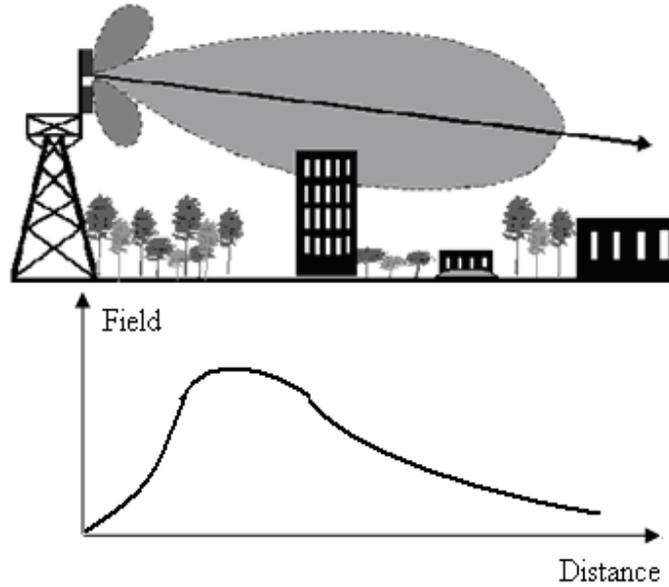

Figure 10. EM field radiations from base station with distance.

6.   EXPERIMENTAL MEASUREMENTS

In this study, emitted electromagnetic radiations of two base stations are measured and investigated. These base stations are in the tower billboard shown in Figure 11 located at the west of Rize city in 41° 2' 12.3" N and 40° 28' 57.3" E coordinates.

Figure 11. Measured base stations area.

In this measurement, by starting from base stations origin, electric field values are measured at same direction for 12 different points. The measurement results are given as a table and plotted figures. Base station company's declarations are compared with the measurements results and theoretical results. Two different stations electromagnetic field values are separated using the devices selective measurement property. Measurement results are checked for government standards and it is seen that the results are suitable for the standards. Company's declarations for base stations are given in Table 3.

Table 3. Company's declarations for two base stations.

Specifications	Station 1	Station 2
Base Stations Address	Boğaz Mah. Balıkçılar Limanı Merkez/RİZE	
Certificate Number	05.053.02464	
Coordinates	42 02 12 N 43 28 56 E	
Telecommunication System	Cell System	
Antenna Height from Earth(m)	24	24
Antenna Gain(dB)	15	15
Maximum Power(W)	10.47	10
Systems Frequency	900	900
Safety Distance(m)	9.74	9.52

For the reliable electromagnetic measurements, measurement time have to be 6 minutes as a standard. Figure 12(a) shows the electric field spectrum of the base stations for 50 meter distance from place level. From this figure, it can be seen that 951.819 MHz frequency has the maximum peak value 625.4 mV/m. Figure 12(b) shows electric field values on 910-970 MHz frequencies interval for station 1 and station 2. Every peak of the figure shows different channel of base stations.
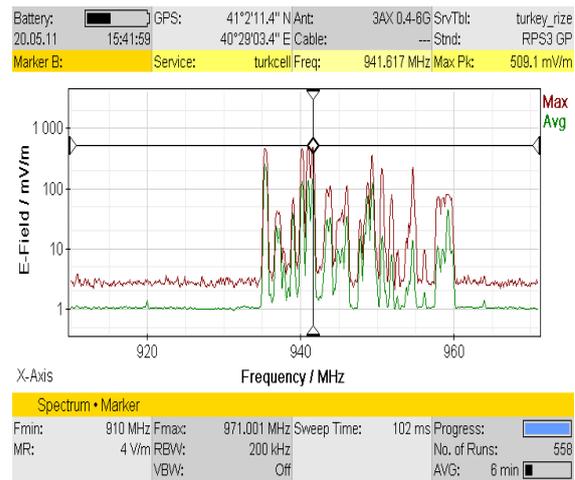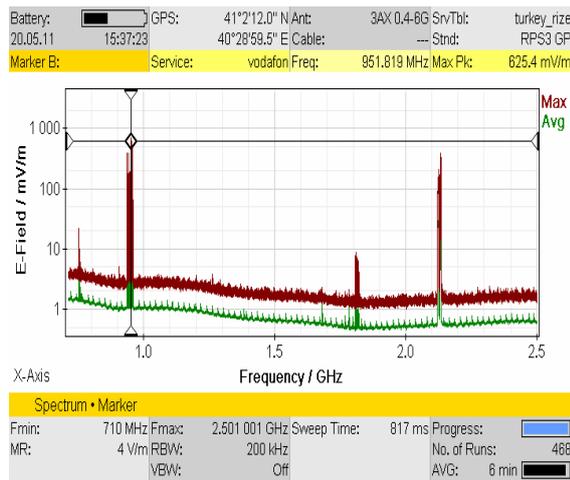

Figure 12. (a) Electric field spectrum 50 meter distance from the base stations. (b) Electric field values for 910-970 MHz frequencies interval.

For these frequency intervals, electric field values are measured from same 12 points as well. The measurement results for two stations are separated each other for bandwidths. Measured maximum electric field and calculated power density values are given in Table 4.

Table 4. Measurement results for two base stations.

Distance (meter)	BASE STATION 1 (935-946MHz)			BASE STATION 2 (946.4-957MHz)		
	Frequency (MHz)	Max. Electric Field (mV/m)	Power Density (mW/m^2)	Frequency (MHz)	Max. Electric Field (mV/m)	Power Density (mW/m^2)
0	940.932	498.8	0.651	949.433	1114	3.248
10	940.930	246	0.158	949.430	1016	2.702
20	941.643	431.2	0.486	948.836	545.7	0.779
30	940.933	592.7	0.919	951.862	855.4	1.915

40	941.613	405.9	0.431	949.402	702.9	1.293
50	941.613	405.9	0.431	949.402	702.9	1.293
100	935.372	664.9	0.157	954.591	336.7	0.296
150	935.403	830.3	1.804	949.438	302.4	0.239
200	935.346	507.3	0.673	954.657	193.7	0.098
300	935.387	436.7	0.499	950.621	276	0.199
400	940.216	350.4	0.321	949.372	205	0.110
500	940.987	170.4	0.076	949.370	204.6	0.109

The measurement results in Table 4 and theoretical results calculated in Equation 1 and 2 for two base stations are plotted in Figure 13 and Figure 14, respectively. Figure 13 shows the electric field result with distance. Figure 14 shows the power density results with distance. The results show that the values in very near field are bigger than expected values. Because of reflections and metallic structure of the tower behaves as an antenna, higher values are measured in very near area. The results in middle field are smaller than expected values, because measurements are evaluated on the place along the station, not along the antenna propagation direction and some antenna loses which neglected. Imagine the place in Figure 10, measurements were made at the ground level, not at the straight line of the antenna on air. Therefore, for the distance close to zero, measured values are a little higher than theoretical values, and then theoretical maximum values are a little higher than measurements in Figure 13 and 14. For long distance measured values are a little higher than the theoretical values because of reflections.

As a result, measurement values for electric field and power density are not bigger than the safety standards for any measurement point where the people live. Using the Equation 1 with Table 2 and Table 3 safety distance from base station can be calculated in Equation 11.

$$d = \frac{\sqrt{30 \cdot 10 \cdot 47 \cdot 10^{\frac{15}{10}}}}{10,45} = 9,74 \; meter \tag{11}$$

From Equation 11 safety distance for station 1 is calculated approximately 10 meter for Turkish public safety evaluation standards are defined using ICNIRP guidelines and this was declared for the last time in 2009. This distance is horizontal distance from the antenna. If station is on a tower or high place, safety distance can be calculated using the theoretical results in Figure 13 for electric field from the ground level.
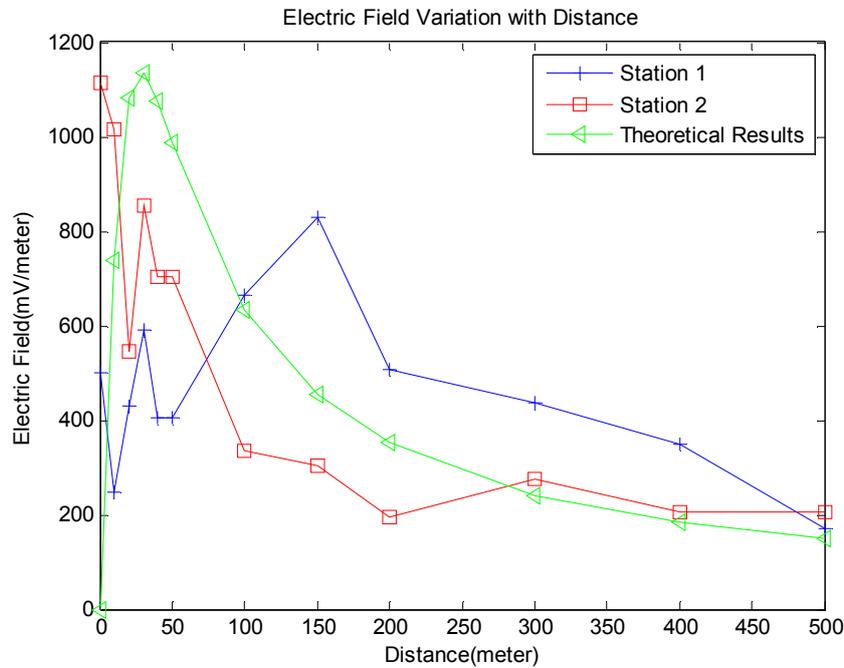

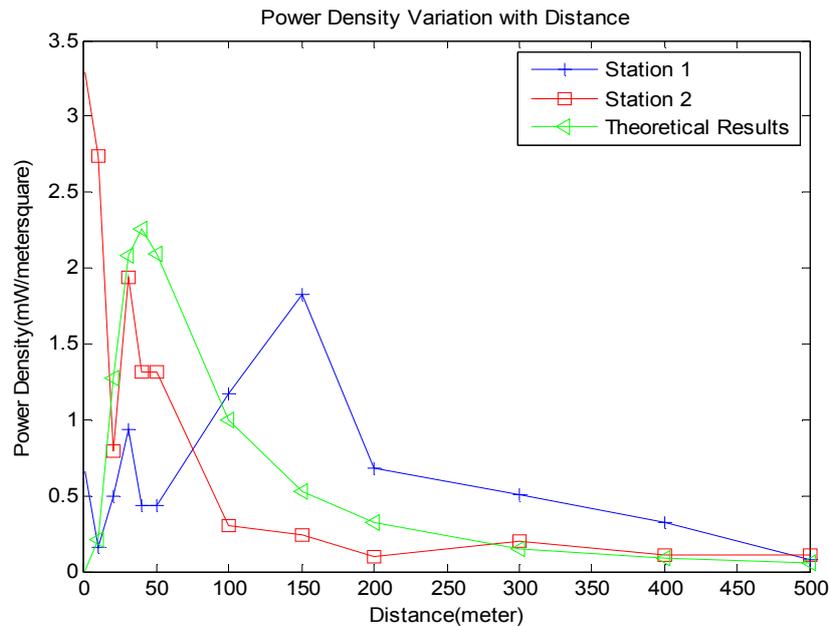Figure 13. The electric field variation result with distance.

Figure 14. The power density variation results with distance.

7. CONCLUSIONS

A detailed review and background information on non-ionizing radiation, measurement equipments, and standards are given. Electromagnetic field measurement systems and experimental results are discussed in detail. For different measurement routines results are compared with standards. Electric field measurements are separated for each two base station using the spectrum analyzer technique. Electric field measurement results are compared with the theoretical results depending on the distance from base stations. Electric field and power density measurement results are compared with the safety distance. Also, safety distance from base station is calculated approximately 10 meter for Turkish standards.

As a future study, it can be measured for different points on a field and located on a map. So, an electromagnetic pollution map can be formed for any place like a campus or city.

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